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by

R. C. Worrest
Environmental Research Laboratory
U.S. Environmental Protection Agency
Corvallis, OR 97333

ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CORVALLIS, OR 97333

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16. ABSTRACT
For years scientists and laymen alike have casually noted the impact of solar ultraviolet radiation upon the nonhuman component of the biosphere. It was not until recently, when human activities were thought to threaten the protective stratospheric ozone shield, that researchers undertook intensive studies into the biological stress caused by the previously slighted short-wavelength edge of the global solar spectrum. Stratospheric ozone functions 220-320 nm waveband as it penetrates through the atmosphere, thus allowing only small amounts of the longer wavelengths of radiation in this waveband to leak through to the surface of the earth. Although this radiation (UV-B radiation, 290-320 nm) comprises only a small fraction (less than 1%) of the total solar spectrum, it can have a major impact on biological systems due to its actinic nature. Many organic molecules, most notably DNA, absorb UV-B radiation which can initiate photochemical reactions. It is life's ability, or lack thereof, to cope with enhanced levels of solar UV-B radiation that has generated the concern over the potential depletion of stratospheric ozone. The defense mechanisms that serve to protect both plants and animals from current levels of UV-B radiation are quite varied. Whether these mechanisms will suffice in the marine ecosystem under conditions of enhanced levels of UV-B radiation is the subject of this report.

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IMPACT OF ENHANCED SOLAR UV-B RADIATION UPON THE MARINE ECOSYSTEM

R. C. Worrest

U.S. Environmental Protection Agency, Corvallis, Oregon 97333, USA

For years scientists and laymen alike have casually noted the impact of solar ultraviolet radiation upon the nonhuman component of the biosphere. It was not until recently, when human activities were thought to threaten the protective stratospheric ozone shield, that researchers undertook intensive studies into the biological stress caused by the previously slighted short-wavelength edge of the global solar spectrum. Stratospheric ozone functions effectively as an ultraviolet screen by filtering out solar radiation in the 220-320 nm waveband as it penetrates through the atmosphere, thus allowing only small amounts of the longer wavelengths of radiation in this waveband to leak through to the surface of the earth. Although this radiation (UV-B radiation, 290-320 nm) comprises only a small fraction (less than 1%) of the total solar spectrum, it can have a major impact on biological systems due to its actinic nature. Many organic molecules, most notably DNA, absorb UV-B radiation which can initiate photochemical reactions. It is life's ability, or lack thereof, to cope with enhanced levels of solar UV-B radiation that has generated the concern over the potential depletion of stratospheric ozone. The defense mechanisms that serve to protect both plants and animals from current levels of UV-B radiation are quite varied. Whether these mechanisms will suffice in the marine ecosystem under conditions of enhanced levels of UV-B radiation is the subject of this report.

Summary

In marine systems, UV-B radiation (e.g., 310 nm) penetrates approximately the upper 10% of the coastal marine euphotic zone before it is reduced to 1% of its surface irradiation level (Jerlov 1976; Baker and Smith 1981). The amount of UV-B radiation penetrating the ocean's surface has long been suspected as a factor influencing primary production. There are numerous researchers who, by comparing productivity in culture bottles having different ultraviolet transmittances, have produced data showing that increased ultraviolet irradiation increased phytoplankton photoinhibition (Steemann Nielsen 1964; Jitts *et al*. 1976; Lorenzen 1979; Smith *et al*. 1980; Worrest *et al* 1980; Smith and Baker 1980a, 1980b, 1981). The sum of this research offers convincing evidence that ultraviolet radiation, at present levels incident at the surface of natural waters, has an influence on phytoplankton productivity as currently measured. It may be that most reports for primary production in

surface waters are overestimated by about 40% as a result of diminished UV-B effects. These diminished effects result from the common use of relatively UV-B opaque glass bottles in the studies.

It has been calculated that near the surface of the ocean (K_{PAR} = 0.1) enhanced UV-B radiation simulating a 25% reduction in ozone concentration would cause a decrease in productivity of about 35.4% (Smith et al. 1980). The calculated integrated decrease in productivity in the upper third of the euphotic zone ($K_{PAR} \cdot Z = 1.5$) would be about 18%. The estimated reduction in productivity for the whole euphotic zone would be 9%. Analogously, if no UV-B radiation were incident at the earth's surface, it is calculated that phytoplankton primary productivity would increase by about 11.6%.

A 10% ozone reduction would result in only a 1% increase in total solar ultraviolet dose at mid-latitudes during the summer (Green et al. 1980). This would be of trivial consequence if radiation throughout the ultraviolet waveband were of equal biological effectiveness. However, when biological sensitivity functions are employed, a very different picture emerges. Integrations of solar spectral irradiances and biological weighting functions show that an ozone reduction would result in a much larger change in radiation calculated to be DNA-damaging (Setlow 1974) than for radiation calculated to be effective in inhibiting phytoplankton photosynthesis (Jones and Kok 1966) in acute radiocarbon uptake studies. For radiation that might inhibit phytoplankton photosynthesis there would only be a 2% increase in effective dose for a 10% ozone reduction (an amplification factor of 0.2). In contrast, for DNA-damaging radiation, the effective increase would be 28% for a 10% ozone reduction (an amplification factor of 2.8).

There are subtle effects of solar UV-B radiation described in the literature which may have a significant impact upon ecosystems. It has been noted that the fecundity of a marine copepod was reduced by nonlethal levels of UV-B radiation (Karanas et al. 1979, 1981). An impact upon reproductive rates was also noted for marine phytoplankton and utilized to determine the effect of enhanced UV-B radiation upon a model ecosystem (Worrest et al. 1981b). Shifts in community composition occurred in the model, a result corroborated by a subsequent study involving naturally recruited marine ecosystems (Worrest et al. 1981a).

The interpretation of changes in community diversity is subject to speculation; however, if the species composition of the primary producers is altered, the quality and possibly the quantity of food present for primary consumption could also be altered. Therefore, organic carbon exchange between

trophic levels could be affected. The impact would be significant if the species which adapted to enhanced UV-B radiation were of lower nutritional value (i.e., if they diminished growth and fecundity of the consumers). If the indirect impact of suppression of primary production upon consumers were linear, a 5% reduction of primary production would result in a 5% reduction in fish production. A question still under investigation is whether the trophodynamic relationships might be nonlinear. For example, there may be an amplification factor involved that results in a relatively greater impact at higher trophic levels than at the primary-producer level. The actual impact of altering the community composition of an ecosystem requires further study.

Reproductive impairment in copepods appears to be a more sensitive measure of UV-B stress than survival. There have been no *in situ* investigations dealing with the effect of solar UV-B radiation on copepods; however, it is believed that exposure levels below those required to affect the organism's survival could alter the population due to effects upon reproductive capability (Karanas *et al.* 1981).

Previous work described dose-rate thresholds in the effect of UV-B radiation on the near-surface larvae of three species of shrimp (Damkaer *et al.* 1980). Additional observations suggested that the total-dose response varied with dose-rate (Damkaer *et al.* 1981). Below an irradiance of 0.002 biologically effective $W \cdot m^{-2}$ no significant effect was noted in activity, development, or survival. Beyond that dose-rate threshold, shrimp larvae were significantly affected if the total dose exceeded about 85 biologically effective $J \cdot m^{-2}$. Predictions regarding impact of UV-B radiation upon shrimp larvae cannot be made without both dose-rate and total dose being considered.

The dose/dose-rate thresholds for shrimp larvae were compared to four-year mean dose/dose-rate solar UV-B irradiances at an experimental site (Puget Sound, Washington, USA), measured at the surface and calculated for a 1-m depth. The probability that the larvae would receive lethal UV-B exposures was low for the first half of the season of surface occurrence, even with a 16% reduction in stratospheric ozone. The long-term effects were not considered.

Information exists regarding the impact of UV-B radiation on finfish raised in hatcheries (Bell and Hoar 1950; Dunbar 1959). Until recently, however, little documentation has appeared in the literature concerning ultraviolet stress upon pelagic fishes (Hunter *et al.* 1981). Solar ultraviolet radiation may be a stress agent for pelagic fish embryos spawned during the winter and located near the surface of the water (Marinaro and Bernard

1966). There is documentation of the impact of UV-B radiation upon anchovy and mackeral eggs and yolk-sac larvae (Hunter et al. 1979, 1981a, 1981b). Growth was directly inhibited in all finfish larvae surviving treatments and the extent of growth inhibition was roughly proportional to the mortality. Thus, a decrement in growth is produced at a lower dose than mortality.

Imprecisely defined habitat characteristics and the unknown effect of a small augmentation on high natural mortality rates are the major barriers to accurate assessment of ozone reduction on marine fish populations (Hunter et al. 1981b). The ratio between relative sensitivity and UV-B penetration in the habitat will be useful in defining vulnerability of marine communities in general. Great caution must be exercised in relating the results of aquatic studies conducted in the laboratory to a natural body of water. The depth of the attenuating water column, degree of mixing, the ratio of photosynthetically active radiation to UV-B radiation, behavioral responses, seasonality of exposure, and the prehistory of the target organisms all must be considered. Although near-surface organisms are affected by UV-B radiation, the impact on the total, productive water column is still unknown.

Although an analysis of risk to the biosphere resulting from enhanced levels of UV-B radiation is fraught with complications and caveats, there is growing evidence that solar UV-B radiation is a stress agent. It has been demonstrated that exclusion of solar UV-B radiation from the current solar spectrum enhances primary production. Although it does not necessarily follow that enhanced levels of solar UV-B radiation will further decrease productivity from current levels, one might assume that organisms do not possess repair mechanisms which function to "pre-adapt" the organisms to levels of radiation not previously encountered.

In view of the other environmental factors that affect species composition and productivity of communities, it is difficult to discern the influence of current fluctuations in the ozone layer or to predict events of the future in the case of a reduced ozone layer resulting from human activities. Most organisms seem relatively well adapted to cope with present-day levels of ultraviolet radiation through molecular repair systems, shielding tissues and pigments, and perhaps other mechanisms. A simple model for the assessment of the possible influence of enhanced UV-B radiation on marine primary production has been developed and utilized to emphasize major uncertainties in present predictive capabilities. Possible nonlinear uncertainties overlooked in the simple model are: (1) the role of the biological weighting function in predictive models and the limitations of ^{14}C-techniques as currently and

routinely used; (2) the possibility of community structure change, due to increased UV-B stress, and the consequent potential for trophodynamic changes in the food chain; and (3) the influence of mixing on estimates of biologically effective doses and photosynthetically active radiation. Any, or all, of these uncertainties are potentially orders of magnitude more important than "linear conclusions" drawn from the simple model. Ultimately, it is the potential impact on a natural population that is of the most concern and it is here that the greatest uncertainties exist. The notion of defining habitat vulnerability and the temporal and spatial variability in UV-B stress for an entire natural population has received too little attention.

In summary, there is a rapidly growing data base which indicates that solar UV-B radiation is a stress agent, even at current levels. Further field studies are required either to corroborate or to qualify conclusions based on results from laboratory investigations or from models. The greatest impact of enhanced solar UV-B radiation may be on the subtle interactions that take place within an ecosystem, interactions which could lead to significant changes in the ecosystem.

Some of the information contained within this paper has been derived from separate reports submitted to the U.S. Environmental Protection Agency by D. M. Damkaer, J. R. Hunter, R. C. Smith, and J. H. Taylor.

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